Flight Surgeon Refresher Course

Section 3: Aeromedical Training

Altitude Physiology

(FSRC303)

ALTITUDE PHYSIOLOGY

Introduction

Air crewmembers operate in an environment that exposes them to hazardous altitudes on a daily basis, posing a serious threat to aircrew safety and performance. Proper management of the effects of altitude can enhance cockpit performance, promote a safe flying environment and ensure successful execution of the mission.

Objectives

a. Describe the characterisics of the atmosphere.

b. Identify the physiological zones of the atmosphere.

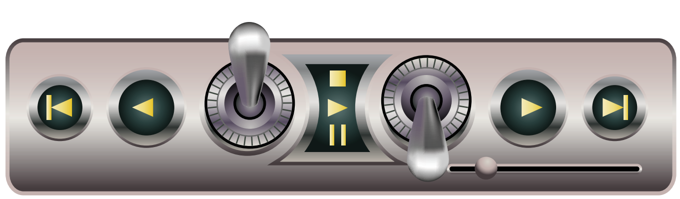
c. List the physiologic effects of hypoxia.

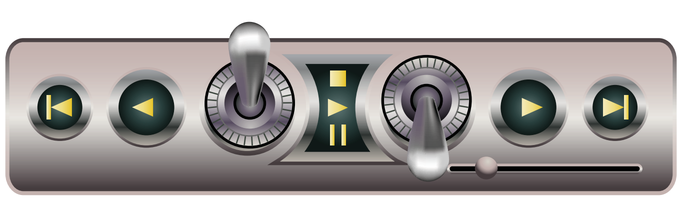
d. Match the types of hypoxia with their respective causes.

e. Describe evolved gas dysbarisms.

f. Differentiate between hypoxia and hyperventilation.

g. Describe trapped gas dysbarism.





What is the atmosphere?

- A mixture of gases that surrounds the earth's surface.
- Consists of a mixture of water vapor and gases that extends from the surface to approximately 1,200 miles.
- Held in place by gravity
- Exhibits few physical characteristics that can be readily observed.
- Shields earth's inhabitants from ultraviolet radiation.

What are the physiological zones of the atmosphere?

Man cannot physiologically adapt to all the physical changes of temperature and pressure, which occur within the various regions. For this reason, the atmosphere is further divided into three physiological divisions. The primary basis for these physiological zones is the pressure changes that take place in the human body. Individual factors alter the altitudes of the physiological zones.

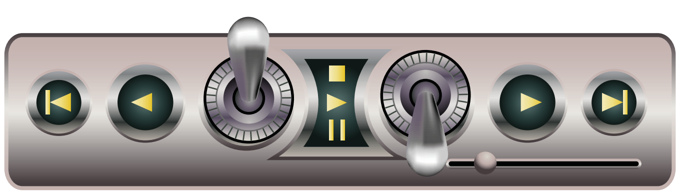
As altitude increase, the total atmospheric pressure decreases thus reducing the partial pressure of oxygen (PO_2). This partial pressure determines the physiologic effect of altitude.

Composition of the atmosphere:

- Nitrogen (N_2): 78%. Most plentiful gas in the atmosphere. Essential building block of life, but not readily used by the body (inert gas).
- Oxygen (O_2). 21%.
- Other gases: 1%. Carbon dioxide (CO_2) - contained dioxide (CO_2) - contained in the other 1% of gases and is essential to controlling respiration. (.03% of that 1% is CO_2.)

Physiological zones of the atmosphere

Efficient Zone	Deficient zone	Space equivalent zone
• Sea level to 10,000 feet. • Most individuals are physiologically adapted to this zone. • Oxygen levels within this zone are sufficient for a normal, healthy person without the aid of protective equipment. • Barometric pressure drops from 760mm/hg to 523mm/hg in this zone.	• 10,000 feet to 50,000 feet. • Noticeable physiological problems, such as hypoxic hypoxia and evolved gas disorders, occur unless supplemental oxygen is used. • Barometric pressure drops from 523mm/hg at 10,000 feet to 87mm/hg at 50,000 feet.	• Above 50,000 feet. • Without an artificial atmospheric environment, this zone is lethal to humans and death will occur rapidly.



Hypoxia

A condition that results from an insufficient amount of oxygen (O_2) in the body. Hypoxia can occur at any altitude as a result of decreased partial pressure of oxygen at high altitudes.

What are the symptoms of hypoxia?

Symptoms are observable by the individual aircrew member in themselves. They vary from one person to the next, and are therefore considered subjective in nature. Examples include, but are not limited to the following:

Air hunger or breathlessness

Apprehension (anxiety)

Fatigue	**Nausea**
Headache	**Dizziness**
Hot & cold flashes	**Euphoria**
Belligerence (anger)	**Blurred vision**
Tunnel vision	**Numbness**
Tingling	**Denial**

What are signs of hypoxia?

Signs are observable by the other aircrew members and therefore, are considered objective in nature. Examples include but are not limited to the following:

Increased rate and depth of breathing

Cyanosis	Loss of muscle coordination
Mental confusion	Poor judgment
Unconsciousness	Slouching

What are the types of hypoxia?

Hypemic hypoxia

- Caused by a reduction in the O_2-carrying capacity of the blood.
- Anemia and blood loss are the most common cause of hypemic hypoxia.
- Carbon monoxide from smoking and exhaust fumes are potentially dangerous to the aviator.
- Nitrates, and sulfa drugs also cause hypemic hypoxia by forming compounds with hemoglobin that block its ability to attach O_2 for transport.

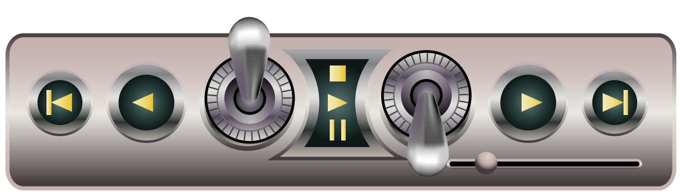
Stagnant hypoxia

- Reduction in systematic blood flow or regional blood flow.
- Such conditions as heart failure, shock and the venous pooling of blood encountered during positive-G maneuvers predispose the individual to stagnant hypoxia.
- In addition, environmental extremes, prolonged sitting and restrictive clothing can produce local stagnant hypoxia.

NOTE: An aircrew member will usually experience similar symptoms every time hypoxia is experienced. This is why the altitude chamber is an excellent training aid!

Histotoxic hypoxia

- Results when there is interference with the use of O_2 by body tissues.
- Alcohol, narcotics, carbon monoxide and certain poisons such as nicotine and cyanide interfere with the cells' ability to use an otherwise adequate supply of O_2.
- Warning! Carbon monoxide is very dangerous--it attacks the body's blood and tissues simultaneously. Hemoglobin has an affinity for CO 200 times greater than O_2.



Hypoxic hypoxia

- Occurs when there is insufficient O_2 in the air that is breathed or when conditions prevent the diffusion of O_2 from the lungs to the blood stream.
- This is the type that is most likely to be encountered at altitude.
- It is due to the reduction of the partial pressure oxygen **(PO_2) at high altitudes.**

What are the stages of hypoxia?

There are four stages of hypoxia. These stages increase in severity and danger as oxygen deprivation increases:

The Indifferent Stage. This stage occurs from sea level to 10,000 feet (34,000 to 39,000 feet with 100% O_2). Hemoglobin saturation for the indifferent stage ranges from 98% to 87%.

It is the mildest stage of hypoxia with the least severe symptoms. The only significant effect or symptom of mild hypoxia in this stage is that night vision deteriorates at about 4,000 feet. The retina of the eye and the central nervous system have a great requirement for oxygen. To begin compensating for this, the heart rate and breathing rate increase at about 4000 feet to improve circulation to brain and heart. Decrease of visual sensitivity of up to 28% at 10,000 feet, varying among individuals.

NOTE: Symptoms of hypoxia become evident at 87% hemoglobin saturation.

The Compensatory Stage. This stage **o**ccurs between 10,000 and 15,000 feet (39,000 to 42,000 feet with 100% O_2). Hemoglobin saturation for the compensatory stage ranges from 87% to 80%.

The circulatory system, and to a lesser degree, the respiratory system, provide some defense against hypoxia in this stage.

Symptoms include increases in pulse rate, systolic blood pressure, circulation rate and cardiac output.

Signs of hypoxia in the compensatory stage include impaired efficiency, drowsiness, poor judgment, and decreased coordination.

Disturbance Stage. In this stage, the physiological responses can no longer compensate for the O2 deficiency, and the organ systems of the body. The disturbance stage occurs between 15,000 and 20,000 feet (42,000 to 42,800 feet with 100% O_2). Hemoglobin saturation for the disturbance stage ranges from 65%-80%.

Hypoxia symptoms become severe at this stage. In the sensory realm, peripheral and central vision are impaired and visual acuity is diminished. The sense of touch (and pain) are diminished or lost. Hearing is one of the last senses to be lost.

Mental capacity is affected - intellectual impairment is an early sign that often prevents an individual from recognizing disabilities. Memory, judgment and reliability, understanding and the ability to make decisions or solve problems are all diminished.

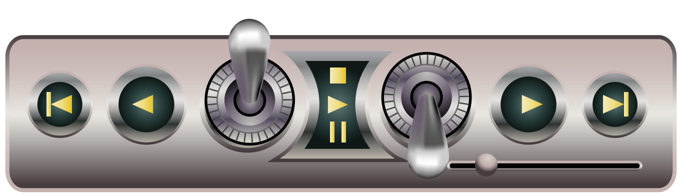
Personality traits are affected. This facet may include the release of “basic personality traits and emotions as with alcohol intoxication. Euphoria, aggressiveness, overconfidence, and depression may be displayed in the disturbance stage of hypoxia.

Performance (psychomotor functions) suffer. These include coordination, flight control, speech and handwriting.

CAUTION: Failure to recognize the signs and symptoms of Hypoxia and take corrective action may result in an aircraft mishap.

The Critical Stage. This stage is rapid and extreme. This stage occurs at 20,000 feet and above (44,800 feet and above with 100% O_2). Hemoglobin saturation for the critical stage drops to less than 65%.

Within 3 to 5 minutes, judgment and coordination deteriorate. The signs become progressively worse as loss of consciousness, convulsions, and death follow in rapid order.



WARNING: When hemoglobin saturation falls below 65%, serious cellular dysfunction occurs; and if prolonged, may cause death.

What factors modify hypoxia symptoms?

- **Altitude pressure.** Determines the PO_2 in the lungs.
- **Rate of ascent.** At rapid rates, high altitudes can be reached before serious symptoms are noticed.
- **Time at altitude** (exposure duration). Usually the longer the duration of exposure, the more detrimental the effect of hypoxia. The higher the altitude, the shorter the exposure time required before hypoxia symptoms occur.
- **Temperature.** Exposure to cold weather extremes reduces the tolerance to hypoxia by virtue of the increase in metabolic workload. Hypoxia may develop at lower altitudes than usual.
- **Physical activity.** When physical activity increases, the body demands a greater amount of O_2. This increased O_2 demand causes a more rapid onset of hypoxia.
- **Individual factors.** An individual's susceptibility to hypoxia is greatly influenced by metabolic rate, diet, nutrition, and emotions (probably most inconsistent factor).
- **Physical fitness.** An individual who is physically conditioned will normally have a higher tolerance to altitude problems than one who is not. Physical fitness raises an individual's tolerance ceiling.
- **Self-imposed stress.** Smoking and alcohol increase an individual's physiological altitude and therefore reduces their tolerance ceiling.

Preventing hypoxic hypoxia at altitude:

- Limit time at altitude (Limits are published in AR 95-1)
- Use supplemental O_2
- Use pressurized cabin (increases partial pressure of O_2)

Treating hypoxia:

- Supplemental O_2
- Descend to a safe altitude

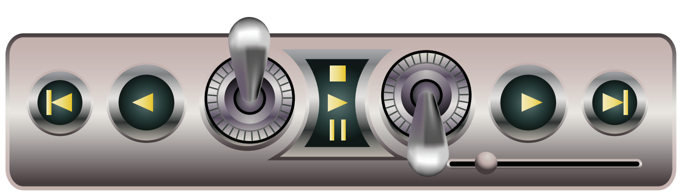
Expected Performance Time (EPT):

EPT is the time a crewmember has from the interruption of the O_2 supply to the time when the ability to take corrective action is lost.

The EPT varies with the altitude at which the individual is flying:

Altitude	EPT
FL 500+	9-12 seconds
FL 430	9-12 seconds
FL 400	15-20 seconds
FL350	30-60 seconds
FL 300	1-2 minutes
FL 280	2.5 - 3 minutes
FL 250	3-5 minutes
FL 220	8-10 minutes
FL 180	20-30 minutes

EPT for a crewmember flying in a pressurized cabin is reduced by approximately one-half after a loss of pressurization, such as in a rapid decompression (RD).



Hyperventilation

Hyperventilation is an excessive rate and depth of respiration leading to abnormal loss of CO_2 from the blood.

What are the signs and symptoms of hyperventilation?

The symptoms are similar to those of hypoxia:

Tingling Sensations	Muscle Spasms	Hot and Cold flashes
Visual Impairment	Dizziness	Unconsciousness

Why is hyperventilation significant?

- Can incapacitate a healthy crewmember.
- Can be confused with hypoxia.

What causes hyperventilation?

- Emotions
  - Fear
  - Apprehension
  - Excitement
- Pressure breathing
- Hypoxia

Preventing hyperventilation:

- Don't panic
- Control rate and depth of respiration

Distinguishing between hyperventilation and hypoxia:

Above 10,000 feet... Assume hypoxia

Treatment: (a) 100% O_2--if available

(b) Descend to a safe altitude

Below 10,000 feet... Assume hyperventilation

Treatment: Voluntary reduction in rate and depth of respiration.

Dysbarisms

In addition to the effects of reduced oxygen at altitude, many physiological effects arise from the clinical effects of the pressure change as we climb in the atmosphere (consider Boyle's Law and Henry's Law). A dysbarism is a syndrome resulting from the effects (excluding hypoxia) of a pressure differential between ambient barometric pressure and the pressure of gases in the body.

What is Trapped Gas Dysbarism?

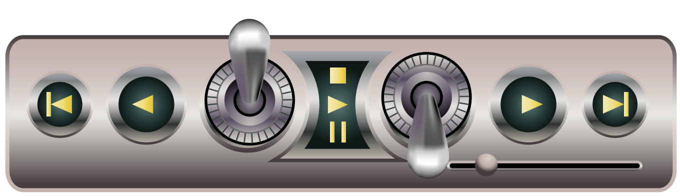
Gases trapped inside bodily spaces and structures expand at higher altitude as pressure decreases. The effects of this expansion can lead to painful and even dangerous disorders in:

- Gastrointestinal tract
- Ear
- Sinuses
- Teeth

What is an Evolved Gas Dysbarism?

Evolved gas dysbarisms, also known as decompression sickness (DCS), occur as a direct result of a reduction in atmospheric pressure. As pressure decreases, gases dissolved in body fluids are released as bubbles. This will cause varied skin, muscle, and possibly neurological symptoms:

- Inert gases in body tissues (principally N_2) are in pressure equilibrium with the same gases in the atmosphere.



- When barometric pressure decreases, the partial pressures of atmospheric gases decrease proportionally, leaving the tissues temporarily supersaturated.
- Responding to the supersaturation, the body attempts to establish a new equilibrium by transporting the excess gas volume in the venous blood to the lungs. However, this is an inefficient system of removal and could lead to an evolved gas disorder.

Evolved Gas Disorders

Several common evolved gas disorders and their etiologies are listed here:

The "Bends." (Decompression Sickness)

DCS occurs when inert N_2 gas bubbles are liberated from tissue as a result of decreasing ambient pressure. When bubbles become trapped in and around the joints, peri-articular pain results. At the onset of bends, pain may be mild but it can become deep, gnawing, penetrating, and eventually intolerable.

Severe pain can cause loss of muscular power of the extremity involved and, if allowed to continue, may result in bodily collapse. The larger joints, such as the knee or shoulder, are most frequently affected. The hands, wrists, and ankles are also common sites. It may occur in several joints simultaneously and worsen with movement.

If Decompression Sickness is suspected:

Immediately perform First Aid Measures:

Administer 100% Oxygen!!!

Seek medical attention and recompression therapy.

Paresthesia (creeps or tingles).

Tingling and itching sensations on the surface of the skin are the primary symptoms of paresthesia as a result of DCS. It is caused by N_2 bubbles forming along the nerve tracts leading to the affected areas.

A mottled red rash may appear on the skin.

The "Chokes" (Pulmonary DCS)

Occurring in the thorax, symptoms are probably caused by innumerable small N_2 bubbles that block the smaller pulmonary vessels.

WARNING: Evolved gas disorders are considered serious and medical treatment/advice must be sought immediately!

At first, a burning sensation is noted under the sternum. As the condition progresses, the pain becomes stabbing with deep inhalation. The sensation in the chest is similar to what one experiences after completing a 100-yard dash.

Short breaths are necessary to avoid distress.

There is an uncontrollable desire to cough, but the cough is ineffective and nonproductive.

Finally, there is a sensation of suffocation; breathing becomes shallower and the skin has a bluish coloration.

CNS Decompression Sickness.

In rare cases when aircrews are exposed to high altitude, symptoms may indicate that the brain or the spinal cord is affected by N_2 bubble formation.

The most common symptoms are visual disturbances that vary from blind spots to the flashing or flickering of a steady light. Other symptoms may be a dull-to-severe headache, partial paralysis, the inability to hear or speak, and the loss of orientation. Paresthesia, or one-sided numbness and tingling, may also occur.

Preventative Measures

These evolved gas disorders can be prevented with the following procedures:

- Denitrogenation (pre-breathing 100% O_2 is required for flights exceeding 20,000 feet)
- Pressurization of cabin
- Limit time at high altitude

Treatment of evolved gas disorders includes:

- Descend to ground level
- Administer 100% O_2 (the best “First Aid”)
- Seek medical advice/assistance
- Recompression therapy (hyperbaric chamber) is standard of care.

What are the risk factors for evolved gas disorders?

Evolved gas disorders do not happen to everyone who flies. Certain factors tend to increase the chance of evolved gas problems and reduce the altitude at which problems can occur.

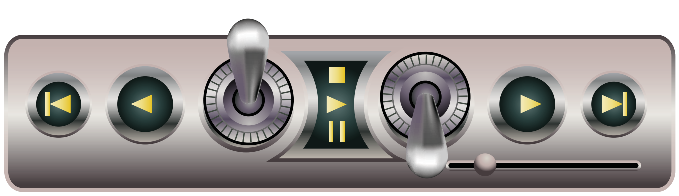
- **Rate of ascent.** The more rapid the rate of ascent, the greater the chance that evolved gas disorders will occur; the body does not have time to adapt to the pressure changes.
- **Altitude.** There is no reliable evidence for the occurrence of DCS with altitude exposures below 18,000 feet; as altitudes increase so does the rate of incidence.
- **Age.** Evidence suggests that individuals in their mid-forties are more susceptible than those in their early twenties.
- **Exercise.** Exercise before ascent will increase the risk of DCS due to increased bubble formation in joints.
- **Duration of exposure.** The longer the exposure, especially above 18,000 feet, the more likely that evolved gas disorders will occur.
- **Repeated exposure.** The more often individuals are exposed to altitude above 18,000 feet (without pressurization), the higher the risk of evolved gas disorders.
- **Gender/Body build.** Due to emotional and political factors, studies are limited and are therefore inconclusive regarding gender and the incidence of DCS. There is no scientific validation that obesity increases the rate of incidence DCS.

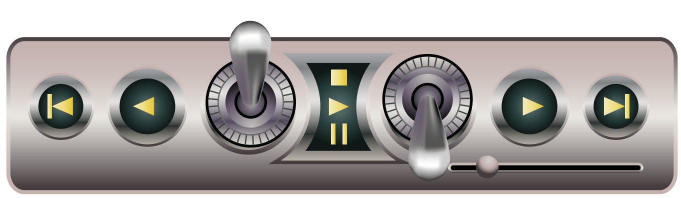
Flying after diving as a crewmember:

In accordance with (IAW) AR 40-8, crewmembers will not fly for 24 hours after SCUBA diving.

During SCUBA diving, excessive N_2 uptake by the body occurs in breathing compressed air.

Flying at 8,000 feet within 24 hours after SCUBA diving at 30 feet subjects an individual to the same factors a non-diver faces when flying unpressurized at 40,000 feet. N_2 bubbles form in the circulatory system.





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